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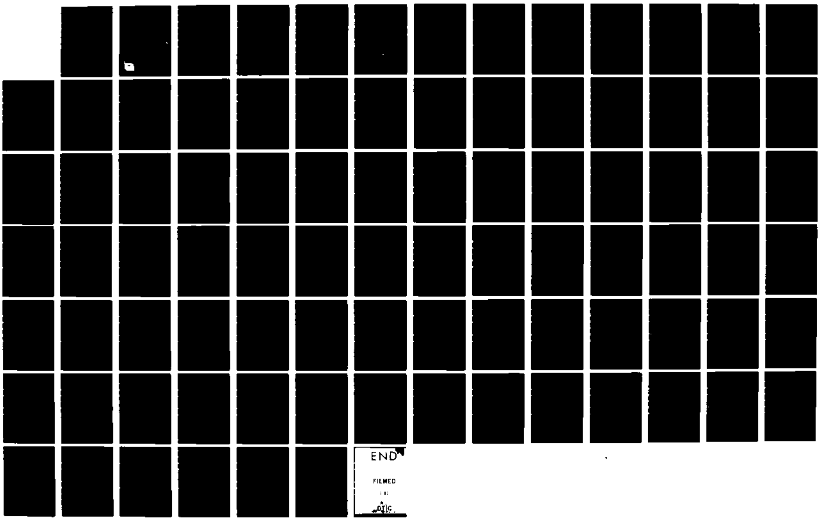

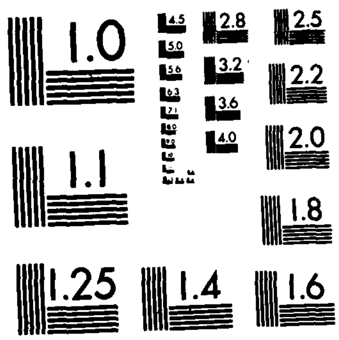

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IDA PAPER P-1703

A SIMPLE MODEL OF POPULATION VULNERABILITY DURING CRISIS RELOCATION

Leo A. Schmidt

January 1983

Prepared for
Federal Emergency Management Agency

This report has been reviewed in the Federal Emergency Management Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Emergency Management Agency.

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The objective of the study is to estimate the cost in survivors of short warning leading to attack during full nationwide crises relocation. A simulation model of traffic flow over the national interstate road network was developed to predict population vulnerability during a crisis relocation. The model predicts large initial rates of reduction in nationwide vulnerability (half the at-risk population is evacuated in

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21 hours) due to the large number of risk centers initially evacuating. Problems arising in risk areas, reception areas, and over the road network to achieve the traffic plan assumptions of the model are discussed. No unreasonable problems are uncovered in achieving the major prediction of the model.

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PREFACE

The research for this report was conducted by the Institute for Defense Analyses (IDA) for the Federal Emergency Management Agency (FEMA) under Contract EMW-C-0749, Work Unit 4112C, dated September 1981.

An objective of the research was to estimate the cost in survivors of short warning leading to attack during full nationwide crisis relocation. A simulation model of traffic flow over the national interstate road network was developed to predict population vulnerability during a crisis relocation. The model predicts large initial rates of reduction in nationwide vulnerability (half the at-risk population is evacuated in 21 hours) due to the large number of risk centers initially evacuating. Problems arising in risk areas, reception areas, and over the road network to achieve the traffic plan assumptions of the model are discussed. No unreasonable problems are uncovered in achieving the major prediction of the model.

This publication is issued in partial fulfillment of the contract.

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SUMMARY

In a serious crisis many different factors could influence a decision to initiate execution of crisis relocation plans. In many scenarios, the possibility of an enemy attack during the crisis relocation emphasizes one important factor in relocation--the rate at which the vulnerability of the population changes during evacuation of risk areas. This paper develops arguments that initiating crisis relocation will not result in an increase in national population vulnerability to attack but, on the contrary, will rapidly decrease its vulnerability.

A qualitative discussion of evacuation problems considers Risk Areas, Host Areas and Road Networks.

Risk Areas

The best shelter which might be available to most people in a risk area leaves them considerably less vulnerable to nuclear weapons effects than exposure in an automobile, which is taken here as the prime means of evacuation transportation. However, many scenarios have sufficiently heavy attacks on risk areas so that even if sheltered in existing buildings, the chances of survival in attacked areas are poor. Moreover, if adequate control of movement within the risk areas can be achieved, the time of exposure to attack while in transit can be minimized.

Host Areas

The prime consideration in reducing vulnerability in reception areas is obtaining adequate protection against

radioactive fallout. Since available fallout shelter in reception areas is generally inadequate, additional shelter must be provided by either upgrading the protection of existing shelter or developing expedient fallout shelter. It is argued that such protection generally could be achieved within a short time after the arrival of evacuees at these centers if the fallout threat is perceived to be sufficiently serious to warrant very strenuous efforts.

Road Networks

The main factor constraining the rate of evacuation is the primary road network leading from risk areas, which is basically the interstate highway system. If access to these highways can be controlled, then flow can be maintained along them with a reasonable degree of confidence. The capacity of an interstate highway for evacuation purposes might be estimated by the product of 3 people per automobile times 1000 automobiles per lane per hour times 2 outbound lanes per road, or 6000 people per hour.

A simple computerized model was developed to simulate travel along the interstate road network, supplemented by estimated travel capabilities over local road networks surrounding risk areas. Reception center limitations along the road network were imposed to guard against unrealistic host area allocations.

The model showed an initial high rate of evacuation, with 37 percent of the initial risk area population evacuated in 12 hours, and 53 percent in 24 hours. After 3 days, 76 percent of the risk area population was evacuated.

The high initial rate of evacuation and consequent reduction in vulnerability was due to the large number of

medium and smaller size risk areas evacuating onto an uncongested road network. Due to the simplicity of the traffic patterns in most areas, considerable confidence may be placed in these early time predictions. In fact, an initial flow rate may be estimated by multiplying 6000 people per road per hour by an average of 4 roads leading from a risk area times 250 risk areas initially evacuating. This gives an evacuation rate of 6 million people per hour - close to the model predictions.

After some time only the large size risk areas are still evacuating, and usually onto generally congested road networks. At these later times a more complex method is needed to realistically estimate traffic rates.

The simple model illustrates that a very different estimate of evacuation time is obtained by concentrating on overall nationwide crisis relocation patterns rather than on the complex problems of a few large centers, e.g. New York or Los Angeles. It also emphasizes that conservative and effective crises relocation plans are possible for most of the nation if adequate control of traffic is possible, and that more detailed planning is required to develop such plans for a few major urban centers.

Chapter I

INTRODUCTION

A nuclear weapon is totally destructive in the near vicinity of the explosion. One means of protection from nuclear weapons effects is to be beyond the immediate vicinity of potential target areas; beyond a distance of (say) 10 to 30 miles from the explosion, the direct effects of the blast wave and thermal radiation have attenuated to a degree where they no longer pose a significant threat to human life, or to buildings. Once removed from direct effects it becomes much easier to protect against the fallout threat. A crisis relocation exploits the reduction of direct nuclear weapon effects with distance by removing people from potential target areas. Planning for such a relocation has become a major element of Civil Defense.

It is recognized by all that the time required for ballistic missiles to travel from their launch areas to their targets is much less than the time to effect a strategic evacuation. No relocation plan could protect against the scenario of a surprise surreptitious attack by an aggressor against our populated areas. Thus Crisis Relocation Planning can not protect against all contingencies.

On the other hand, given enough time an evacuation can be completed. Surveys indicate that there are enough resources in reception areas (at least in most areas) to provide support for the evacuated population for some period of time and to provide expedient fallout shelter. Thus in a scenario where adequate warning is provided to allow an evacuation to be

completed, the immediate casualties from a nuclear weapon attack could be held to a relatively low level.

Practically, an endless variety of scenarios could be imagined leading up to a nuclear attack upon this country. In Reference 1 a set of scenarios is developed to cover a spectrum of possible types of attacks. From Reference 1: "If there is a single theme which runs through all the scenarios, it is that of the unpredictability of events and the ambiguousness of indicators. The standard military war-game, with its steadily rising orchestration of events, leading to the inevitable crescent of nuclear attack upon the United States, has no place in the real world for which Civil Defense must prepare. It is the very element of uncertainty which constitutes the crux of the Civil Defense problem."

A decision to relocate away from a target area, whether made at a personal or governmental level, involves major disruptions of normal ways of life. Presumably, it would only be made when the perceived threat of an attack is both serious and imminent. The very ambiguousness of the indicators of a possible attack will render its actual occurrence uncertain, and the timing for such an occurrence even more so. The decision maker, private or public, would have no assurance that an evacuation could actually be effected before an attack came. If, in fact, a decision to evacuate would result in large numbers of people being in exposed situations in transit when an attack came, attempting a strategic evacuation would be counterproductive. The timing of the change in national vulnerability during an evacuation might, then, seriously influence a decision concerning when and how to effect an evacuation. The rate at which the vulnerability of the county changes when an evacuation starts is the question addressed in this paper. The focus is upon that aspect of the evacuation

which is probably the most critical and also most susceptible to analytic treatment, namely the traffic bottlenecks leading from the risk centers.

Also developed in this contract but not used in this paper is a transportation allocation algorithm which was conceived by E. Pearsall of Bushnell, Pearsall and Trozzo Associates and which has been used as a basis of developing optimal traffic allocation algorithms for predicting traffic flows in United States transportation networks (railways, roads, and waterways). The optimal flows are obtained from a solution of the Linear Programming Transportation algorithm. This model uses as input data a definition of risk and host areas and a road network consisting of a set of nodes (road junctions) with connecting links (roads). The risk areas are based on current FEMA definitions of conglomerates (of political subdivision). The host areas can either be defined internally by the model or are host areas associated by FEMA with specific risk areas.

The road network was developed by IDA for use in an evacuation analysis. Since counties are usually used to define host areas, the network requires that each county have at least one node in the network. Most of the counties have only one node, but about 20 percent of the nodes are additional nodes added to the basic county nodes to represent critical road junctions. The links represent all interstate highways, almost all U.S. federal highways and the most important state highways. There are a total of 7924 links and 3720 nodes in the network. The network was designed to be the minimum possible to adequately represent major evacuation routes. The reader is referred to this other model for situations more complex than can be adequately treated by the model described in this paper. However, the basic conclusions

of this paper can be arrived at without recourse to this more complex model. A supplement to this report describes this more complex evacuation model in detail along with examples of its use.

A much more simple model has been developed here to explore the general range of results expected. As will be seen, it predicts a rapid decrease in national vulnerability during the initial phase of an evacuation. This is done in a way which can be substantiated by elementary arithmetic calculations.[1] The model is described in Chapter III of this paper, and results from its use in Chapter IV. The next chapter provides a background by discussing the factors affecting the three major parts of the evacuation process--the risk areas, the host areas, and the travel between them. This discussion, and the rest of this report, only addresses the evacuation problem until the time the population is relocated in the host areas. Maintaining the country in an evacuated posture is not considered here.

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[1]They could fit on the back of an envelope if necessary.

Chapter II

DISCUSSION OF THE EVACUATION PROCESS

This chapter will discuss some features of the evacuation process as a background to the specific model described in the next chapter. It will emphasize those features of the process which most strongly influence vulnerability. The three main subjects are the risk areas, the host areas and the transportation between them. A final section discusses the overall process in relation to scenarios.

A. RISK AREAS

1. Definition of Risk Areas

Two general criteria may be used to select areas at risk from military attack: 1) the area is of direct military interest to the enemy in a strategic war or 2) the area has a substantial concentration of population and economic resources. The former category could include silos holding intercontinental ballistic missiles, airfields habitually holding or capable of holding intercontinental bombers, ports for sea-launched ballistic missile submarines, nuclear weapon storage sites, and command and control facilities.

The 1970 census defined urbanized areas are a means of identifying major population clusters.[1] In 1970 there were 247 urbanized areas with a total population of 123 million people, which represents 58 percent of the total U.S. population. These areas also represent an even larger fraction of the manufacturing capability of the United States.

FEMA has constructed a set of 317 risk conglomerates which include both military targets, urbanized areas and some cities too small to be considered as urbanized areas in the 1970 census. Some FEMA conglomerates represent more than one urbanized area, therefore there are about 90 areas in the FEMA list in addition to the urbanized areas used here. Of these, about two-thirds represent military targets. The additional areas contain about four percent additional population at risk over the urbanized areas used here. The urbanized areas therefore represent almost all of the population to be evacuated. Moreover, the problem of evacuating the additional risk areas is generally simpler than for the urbanized areas due to their smaller size and population density. Thus, estimates of the vulnerability of urbanized areas may be taken as representative of the major risk areas.

2. Population Vulnerability in Risk Areas

Under normal conditions the people in an urbanized area are in a great variety of vulnerability conditions either during a normal working day or at night. Under severe threat of nuclear attack, a prudent person staying in a urbanized

[1] Standard Metropolitan Statistical Areas are also based upon concentrations of population. Urbanized areas only include densely settled areas and are more appropriate for these purposes of defining areas at risk than SMSA's, which include the entire county containing some portion of a population cluster.

area might be expected to take some measures to decrease his vulnerability. This would especially be the case if he received tactical warning of an attack in progress over radio or television. Thus, for example, a large fraction of the population in residences might be expected to be in the safest corners of basements, and at least shielded from flying glass or projectiles. Assigning overpressure numbers to average vulnerability is at best a nominal estimate, but mean lethal overpressures might be doubled from unwarned estimates, say from 3 or 4 psi to 6 or 8 psi. Lethal or injury radii might be decreased by 50 percent and lethal or injury areas by a factor of two.

On the other hand, those in the process of evacuating would be in the open or in transportation vehicles. The degree to which cover could be found after receiving tactical warning is problematical. Injury from translation, from debris, and from thermal radiation could all be possible. Estimates of nominal mean lethal overpressures could possibly be half of that for the population in nominal protection and a quarter of that for population in an alerted mode.

Suppose for the purposes of an estimate there are 50 miles of evacuation routes in a city, and that these routes are filled with people leaving the city. There would be 5280/25=200 cars per lane per mile. Assume 4 lanes per route and 4 people per car. Then one obtains 50x4x200x4=160,000 people who might be on in-city evacuation routes, possibly 10 to 20 percent of the population of this nominal sized city.

Estimates of how much of the population is in an exposed mode are strongly dependent upon the discipline of the evacuation. In an efficient evacuation people would leave their dwelling places, proceed without excessive delay to an access point for an evacuation route, and then proceed in a

reasonably good traffic flow along an evacuation route out of the risk area. Suppose the evacuation route could support a flow of 1000 vehicles per lane per hour at a flow rate of 30 miles per hour. Then along each mile there would be $\frac{1000}{30}$ or 33 vehicles. This is 1/6 the number of vehicles that would be exposed under maximum congestion conditions; estimates of exposed population could be made which would be under five percent of the total population. At the other extreme one could imagine choked road flow leaving the city and a panicky population mostly in the streets attempting to get access to the evacuation routes. In this situation large fractions of the population would be in an exposed posture.

The number of fatalities expected in a city is dependent on the vulnerability of the population and upon the intensity of the attack. Also, the type of attack depends upon the attack intentions which, of course, are unknown. One method of estimating what an attacker might do is to assume his intentions are to maximize the number of blast fatalities from those weapons targeted at cities. Reference 2 calculates the distribution of weapons against targets assuming an optimized attack against population, and Reference 3 describes the distributions of the attack over typical targets. From Reference 2 it is seen that heavy attack intensity may be expected over large cities; for exammple, in a 5000 megaton counterpopulation attack, fatality levels in large cities are 85 percent. Illustrations of such optimized attacks in Reference 3 indicate that no portion of a city is left relatively unscathed. In smaller cities the lower population densities would lead to lower attack intensities and thus lower fractions of fatalities. The minimum size of the weapons which might be used, however, could still impose a large fraction of fatalities everywhere in the city. These

results imply that even at higher levels of protection, the fatalities in urban areas are very high. Lower levels of protection would not significantly increase fatalities because attack intensities are so high. From this viewpoint an exposed population is not detrimental because of the universally high risk level.

Another objective often used to define an attack is the maximization of economic value destroyed. For attacks against specific types of economic capability, e.g., petroleum refining, the attack would be concentrated against those areas containing that capability. However, for more generalized risk calculations the entire economic capability should be considered. Here it is found that the optimized attack intensity distribution between cities does not vary greatly than that from an optimized attack against population.[1]

An attack optimized against economic capability would presumably be concentrated against central business districts, large industrial plants, industrial parks, transportation and utilities. Damage to residential areas or damage to industrial routes would be incidental to the primary purpose of the attack. The degree of damage would depend upon vulnerability levels, the proximity to economic targets, and

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[1]There is a slightly higher tendency to attack more densely populated cities because of the relatively greater concentration of industry, but for the purposes of this discussion these differences can be ignored.

weapon yields.[1] No single characterization of risk can be given, for in many places industrial and residential zones are closely intermixed, while others have large residential areas well separated from potential economic targets. The increase in vulnerability of an exposed population in the process of evacuation would serve to reduce those safe areas of the city which are sufficiently far from possible aimpoints.

Using the assigned vulnerabilities of 3.5 psi for exposed population and 7 psi for non-exposed population, distances from a weapon at which these pressures occur can be obtained from Reference 4. These distances are given in the following table for air bursts and surface bursts.

Weapon Yield (MT)	Population Posture	Distance for Air Burst (Mile)	Distance for Surface Burst (Mile)
.05	Exposed	1.9	1.4
	Protected	1.2	0.9
1	Exposed	5.1	3.0
	Protected	3.3	2.4
5	Exposed	8.7	6.5
	Protected	5.7	4.1

An air burst would be used to maximize the area covered by an overpressure of 10 psi, adequate to inflict severe damage on most industrial facilities. A surface burst would be used to completely obliterate the area near the impact point. From the table it is clear that an air burst will have a lethal radius 35 to 40 percent greater than will a surface burst.

[1]With small weapon yields damage is more concentrated in the targeted facility. With larger weapon yields not only the facility itself, but large areas surrounding it are all damaged. In the latter case large fractions of the city area are damaged even though they are not specifically targeted.

The prime variation in distance in the table is due to yield variations. The 50 kiloton yield (0.05 megatons) may be taken as a yield associated with missiles with multiple warheads. In this case the table indicates lethal effects extending no more than two miles from a target facility. For many cities a large fraction of the residential area would be beyond the radii. The yield of one and five megatons may be taken as typical of missiles with a single warhead. A distance of five miles from targeted facilities associated with five MT yields could cover appreciable fractions of the residential parts of target areas.

For people in the open, the direct thermal radiation would be a source of excessive burns. Reference 4 indicates two to three cal/an^2 of radiant exposure to produce first degree burns on exposed skin. For an air burst these would occur at about three miles for a 50 KT weapon, ten miles for a one MT weapon, and 18 miles for a five MT weapon. Thermal radiation for the smaller yield weapons is not a threat for appreciably greater distances than the blast threat, but for larger yield weapons it would cover most of a city area. Upon receipt of tactical warning, a population in the process of evacuating would have to find protection from the thermal flash or suffer a high likelihood of burns.

In addition to the immediate threat from thermal radiation is the threat from fire ignited by it. The magnitude of this threat is partly dependent upon the construction of the areas affected and partly upon weather conditions. It could range from a relatively inconsequential threat to an overwhelming one. In particular, surface winds could cause a mass conflagration to travel downwind into otherwise lightly damaged areas.

If weapons are surface burst, the threat due to direct thermal radiation is reduced, but the threat due to nuclear radiation from fallout becomes serious. Again the areas downwind of an explosion would likely be exposed to a lethal threat unless adequate radiation shelter were available. In this case, however, even the basements of residences might be inadequate to provide adequate shielding.

The preceding recital of weapons effects illustrates the problem of predicting the effects of nuclear weapons. The variables include:

- The selection of target types and specific targets by an attacker.
- The selections of yield and height of burst by an attacker.
- The weather.

Items varying from city to city are the locations of evacuation routes and residential areas relative to potential target areas.

In many situations, traffic on evacuation routes may be controlled to minimize the congestion and therefore time spent adjacent to likely target areas. Thus, for example, an access ramp to an urban freeway in a residential area would be preferred to access next to an industrial area. The control possible over the evacuation process will strongly influence what can be achieved keeping risk area vulnerability as low as possible during the evacuation process.

Finally an attack that is restricted to military targets may have weapons impacting on the outskirts of urban areas, for example on an airfield used as a bomber base. Only that portion of the urban area near this target would be severly affected by this type of attack. The discussion of distance

on effects for economic attack may also be applied to this type of target.

3. Vehicle Availability for Movement from an Urban Area

Under normal conditions the preponderance of travel is by private passenger automobile. It is reasonable to expect that during a crisis relocation this mode of travel will still carry most of the movement. The following table from Reference 5 gives intensity of travel in billions of passenger miles for 1979.

Private Automobile	1287
Domestic Airways	213
Bus	27
Railroads	12
Inland Waterways	4
Total	1543

According to this table, 83 *percent* of all passenger travel is by private automobile. The average length of an airway trip is 1088 miles (Reference 5); this is longer than the average automobile trip, so in terms of number of trips rather than trip miles, the preponderance of passenger automobiles would be even greater. Using a 1979 population of 225 million gives an average intensity of automobile travel of 16 miles per person per day, or with an average household size of 2.75, 44 miles per household per day. Reference 5 gives the following percentages of number of automobiles from 1977 by occupied housing units.

	Average	In SMSA	In Central City
1 Car	47.5	45.3	45.2
2 Cars	28.8	29.6	22.6
3 or More Cars	7.8	8.2	5.7
Total With Cars	84.1	83.1	73.5

In terms of total cars, even in central cities the total is 1.07 cars per household. Nevertheless, on the average about one quarter of the central city residents could need transportation in something other than their own cars.[1]

A substantial portion of intercity freight transport is also over highways. For example, for intercity freight Reference 5 gives the following amounts in billions of ton miles:

Railroad	927
Motor Vehicles	628
Inland Waterways	420
Oil Pipelines	605
Airways	5

In 1980 there were a total of 104 million cars and 26.2 million trucks in use. With these cars the 1970 urbanized area population of 118 million could be transported with an occupancy of 1.13 people per car. Of the trucks, 22.3 million are light trucks of 10,000 pounds or less, primarily pickup and panel trucks.[2] Of the four million heavier trucks, one million are utility trucks or vans. These trucks probably could be used for transporting people, however, the displacement of normal deliveries in a crisis relocation will probably require full use of these vehicles to transport goods.

[1]The number of households without cars is concentrated in large eastern cities where the demand for other means of transportation is correspondingly higher.

[2]In 1976, light trucks were available to 11 percent of the households in central cities (Reference 11).

In order to transport evacuees without passenger cars available, organized sources of vehicles chould be used. In intercity bus lines there are a total of 22,000 buses. Assuming 50 passengers per bus gives a capacity of 1.10 million passengers. Reference 5 gives 54,500 buses in intercity passenger transit. (Of these about 42,000 are in urbanized areas.) Again assuming 50 passengers per bus gives a capacity of 2.7 million passengers. School buses transport a total of 6.9 million elementary school children and 3.3 million secondary school children each day. Assuming each school bus normally transports two bus loads of students per day gives a capacity of 5.1 million passengers. The total bus capacity thus might be estimated at 8.9 million passengers. Assuming further 60 percent of this capacity could be utilized and two round trips a day could be accomplished[1] would give a transport capability of 10.7 million people/day.

Reference 5 gives a total of 2200 rail intercity passenger cars in operation. Assuming 100 passengers per car would give a transport capacity of 0.2 million passengers. A much larger capacity is available if part of the stock of 376,000 box cars could be put to use. Assuming 100,000 box cars could be used and 100 passengers per car gives a capacity of 10 million evacuees.[2] Data from Reference 5 allow calculating normal traffic of 3000 trains/day. Assuming 3000 trains/day all devoted to moving evacuees from urban areas results in train lengths of 33 cars, which is readily achievable. Of course, a disruption of normal operating procedures would occur. Rail systems are often vulnerable to

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[1]A round trip of 300 miles and an average speed of 30 miles/hour plus two hours loading and unloading time would give two trips/day.

[2]There are 27,900 locomotives, so this should pose no shortage.

breakdowns, and under these conditions would be even more vulnerable. If the box cars can be made available, the weather makes their use feasible, and station access can be devised so that loading can be expeditiously performed, the movement of 10 million people per day appears feasible.

Reference 5 shows 293 million revenue passengers enplaned per year, or an average of 0.82 million per day in normal operations. The average trip length is 732 miles. In an evacuation the combination of shorter distances flown and emergency operations should allow a greater passenger rate by some factor. Assuming a factor of 3-2/3 yields a total of three million passengers per day.

Adding passengers from these three modes gives 8.9 million by bus plus 10 million by rail plus 3 million by air, or 21.90 million people per day under the assumptions mentioned.[1] Assuming that all of the people in households without cars need transportation by one of these modes, then 118 x (1-0.73) = 32 million people would be involved. Under these assumptions, 1.45 days would be required. Certainly a well organized effort would be needed to achieve these rates. The author will leave the judgment of the optimism of these assumptions to the reader.

One final evacuation method should be mentioned, the one with greatest historical precedent, namely walking. If the cities in the United States are listed in order of decreasing population the radius in miles of the i^{th} largest city can be given roughly by $r = 25/\sqrt{i}$ (see Reference [2]). For the largest city, r = 25 miles. For i=10, r = 8 miles. A person

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[1]Additional capacity might be available on motorcycles, bicycles, off road vehicles and boats.

living at random in a city might have to walk two-thirds this distance to reach the cities edge, and then another 10 miles to be away from nuclear weapon effects. Another possibility would be to drive to near the city edge, leave the car when further driving becomes unpractical, and then begin to walk.

A soldier is expected to be able to march 20 to 25 miles in a day. Due to his training he is in better physical condition than the average evacuee, however a walking distance of 15 miles a day might not be unreasonable. Thus a days walking from the city edge could remove someone from immediate weapons effects. Walking for a day and a half or two could remove almost everyone in adequate physical condition from direct nuclear weapon effects.

It goes without saying that the problems of sustaining a walking population would be extreme. Transporting people to identified reception centers would be a preferred solution. However it would almost be impossible to prevent people from walking if they wished. A combination of adequate weather, jammed evacuation routes, and a high level of fear of nuclear attack might convince many people to adopt this solution regardless of the desires of authorities. There are certainly historical precedents for large fractions of population adopting this solution to flee from some perceived impending evil.

4. Availability of Roads in Urbanized Areas

The locations and configurations of freeways and expressways in cities are many and varied. However, all of the largest urbanized areas have some expressways serving the central business district, and many of the smaller urbanized areas also do. Almost all of the urbanized areas have limited access highways serving them (even though for possibly 30

percent, these highways are on the fringes of the cities). In the majority of the urbanized areas the intercity expressways connect directly with the intercity limited access highways; in some the connection is from a circumferential highway around the city. Thus for most urbanized areas a reasonable traffic strategy would be to load freeways as they pass through the city and then let this traffic flow directly over the interstate system towards the evacuation areas.

The following table, from Reference 5, gives mileage and travel in Daily Vehicle Miles Traveled for the urbanized area road system.

Category	Miles (Thousands)	DVMT (Millions)
Primary Arterial	46	1185
Interstate	8	422
Other Freeway, Expressway	5	219
Minor Arterial	49	405
Collector	48	182
Local	306	268
Total	462	2681

Assuming 118 million people in the urbanized areas or 118/2.75 = 42.9 million households gives an average of 47.5 miles travelled per household per day. Of this, 14.9 are traveled on freeways. This value is not greatly different from the distance in a city that evacuees would have to travel on a freeway in leaving the city, indicating that the load on urban freeways for the segment of travel in the city is not expected to be greatly larger than normal usage.

A characteristic of older parts of cities is to be laid out in a more or less rectangular network of streets with frequent minor arterial streets interspaced. In the absence of natural barriers (e.g. rivers) or artificial barriers (e.g.

railroad yards) this network will allow travel throughout the city. (Many recent subdivisions contradict this feature. These have one or two entrances onto an arterial street but no connections with adjacent subdivisions. Thru traffic is thus restricted to the arterial roads.) The capability of the city street system is adequate, usually, to allow free travel to the fringe of the city without using the expressway system. Thus it is reasonable to assume that the city road system can feed the rural non-freeway road system with all the traffic it can sustain. The capability of the combined interstate-local road system in the rural area surrounding a city thus becomes the critical element determining the maximum rate of evacuation flow.

B. HOST AREAS

The allocation of evacuees to host areas is a compromise between minimizing travel distance and minimizing the additional burden on the facilities of a hosting area. For more crowded sections of the county, typical maximum travel distances from large evacuating areas might be 200 miles, and typical hosting ratios (ratios of relocated to indigenous population) are two to three[1]. The allocation of evacuees (all else being equal) is at equal hosting ratios since the facilities available for the evacuated population tend to be proportional to the local population.

While the overcrowding of host areas will pose serious inconveniences, preliminary indications are that local resources in host areas are adequate to maintain the augmented

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[1]In some places, e.g. Southern California, with a large urban population and small rural population, much larger travel distances and hosting ratios have to be accepted.

population, at best for several days. In most areas, congregate care facilities (such as schools, churches, municipal buildings, stores, and factories) are adequate to provide shelter, sanitary and feeding facilities without extreme overcrowding. After some time local supplies will become exhausted and replenishment from other areas will become critical. This study is restricting itself to vulnerability from nuclear effects, not economic vulnerability, and will not address these problems. It is recognized that the dislocation of goods deliveries from normal places will place additional burdens on transportation. However these deliveries will mostly occur after the great burden of population relocation is accomplished and should not contribute significantly to transportation bottlenecks.

The major threat to host areas from nuclear weapon effects is fallout. The magnitude of the threat will depend upon the location in the country and the number of surface bursts in an enemy attack. Protection factors needed in fallout shelters could range from nominal value (five, for example) to extreme ratios, say 100, depending upon these variables. The nature of the enemy attack will not be known beforehand, nor the wind pattern on some future day, so there will be an impetus towards providing high levels of protection just in case.

In general, rural areas tend to be deficient in buildings which can be used as fallout shelters. In many areas high quality shelter is not available in sufficient quantity to protect the resident population, much less the evacuees. Congregate care facilities are typically single story

buildings with light roofs. Many cannot provide more than nominal amounts of high quality shelter space.

Two means are available for providing additional fallout shelter, upgrading the protection of existing facilities and constructing expedient shelter. The vulnerability of the evacuated population will be reduced in proportion to the speed with which these emergency measures can be accomplished. This rate is partly dependent upon the equipment and personnel available, and partly dependent upon the degree and determination to provide adequate fallout shelter and the organization of the effort to do so.

The fallout protection of existing single story structures is improved primarily by constructing earth bunkers around the walls of a building, and adding earth to the roof. In order to do the latter, additional supports for the roof are needed. Those would require timbers shored into place at frequent intervals. The exact requirements and best means for accomplishing them will vary from structure to structure, and a fair degree of expertise is needed to accomplish the necessary engineering. A quite substantial amount of earth movement is required which could be accomplished only with great effort without mechanical earth moving equipment. Moreover, the structure which is upgraded for fallout protection will not be in condition for its normal uses after an emergency until a considerable amount of restoration work is done.

Surveys have indicated that there is a considerable potential for upgrading existing structures in rural areas during an emergency. Moreover, equipment and personnel (especially where augmented by evacuees from risk areas) are available to accomplish this upgrading in reasonable time periods. The motivation to undertake this construction effort

will depend upon the perceived risk from fallout, which certainly will partly depend upon the scenarios of the threat causing the evacuation.

A second method of providing fallout protection is through the construction of expedient fallout shelters. Reference 7 describes several such shelters. These shelters were for occupancy by from four to ten persons. Reference 7 describes tests in constructing such shelters from which it concludes that a four-person shelter could be constructed by two normally active adult males in under two days (36 hours in the examples) following specific shelter construction plans and using materials expected to be locally available, or carried in an evacuation journey.

The basic design of most of the shelters described in Reference 7 consisted of an earth trench covered with some supporting material for a roof; wooden poles or house doors were suggested in two designs. This supporting material was in turn covered with earth to provide radiation shielding. Specific suggestions are presented for entranceways, ventilation, and other requirements. The effort required per shelter space, materials per shelter space, and equipment needed are all less, in general, than for upgrading existing structures. The maximum size for such shelters should be 10 occupants (Reference 7), for more people additional shelters should be built. Using these numbers, a natural unit for construction and occupancy of such shelters are the occupants of a few evacuating vehicles, as opposed to the larger numbers typical of identifed shelters or upgraded existing structures.

The construction of expedient shelters would not involve serious mutilating of existing buildings, so there would not be resistance to their construction on this basis. On the other hand their effective construction does require

previously made plans and preparations (e.g. shovels, picks, rope, bedding materials) and considerable effort. Moreover, these shelters are probably not as pleasant to live in as upgraded existing structures and probably considerably less pleasant than a congregate care facility. However, after tactical warning of an attack, several hours would usually be available to move to shelter before fallout arrival; thus the construction of such shelters would require serious intent. As with structure upgrading, the scenario underlying the evacuation would strongly affect such motivation.

The conclusion the author reaches from the previous discussion is that the provision of adequate fallout protection is feasible under most circumstances, and that people could be sheltered within two days of arriving at a host area. In some situations shelter could be available as soon as evacuees arrive at a host area. Without further study, and possibly without some pilot experimentation, a further quantification of the probability distributions of time requirements (or fraction receiving shelter) does not seem warranted. It should be emphasized again that in estimating vulnerability, only the provision of physical protection of shelter has been discussed; in particular, radiological monitoring, communications, life support and host area organization have not been mentioned. The importance of pre-attack planning cannot be emphasized too strongly as an important component in reducing host area vulnerability.

C. EVACUATION ROAD NETWORK

This section will discuss the road network for travel between risk areas and host areas. As mentioned earlier, the main bottleneck to traffic flow is usually the road network in the rural area just surrounding an urbanized area. This shall

be studied here in two parts--the network of major intercity arterial highways, usually of interstate quality, and the network of secondary roads which can be used to supplement the traffic flow over the major highways.

1. Freeways

Most urbanized areas are served by some interstate highways. A typical configuration for smaller or intermediate-size urbanized areas is two interstate highways, one running in a general North-South direction and the other in a general East-West direction crossing near the city center. There are thus four high quality roads leading from the city. Larger urbanized areas typically have additional interstate quality highways leading from them.

The Highway Capacity Manual, Reference 8, is recognized as a basic source used when estimating road capacities. In the Highway Capacity Manual a capacity flow under ideal conditions for a interstate quality highway is given as 2000 vehicles per hour per lane of traffic. However this ideal traffic capacity may be degraded by a number of factors.

As traffic flow increases on a multilane road, the difficulty of faster cars switching lanes and passing slower cars also increases. There is a general slowing down of traffic. The upper curves of Figure 1 from Reference 8 illustrate this decrease of speed as volume increases. This general trend continues until the peak road capacity is reached. In this figure the peak flow rate is the ideal flow rate of 2000 cars per lane per hour. The dashed line at the bottom of the figure represents a choked unstable flow regime with great traffic congestion. Some small disturbance could send the flow from the maximum rate into this unstable regime where the volume is greatly reduced.

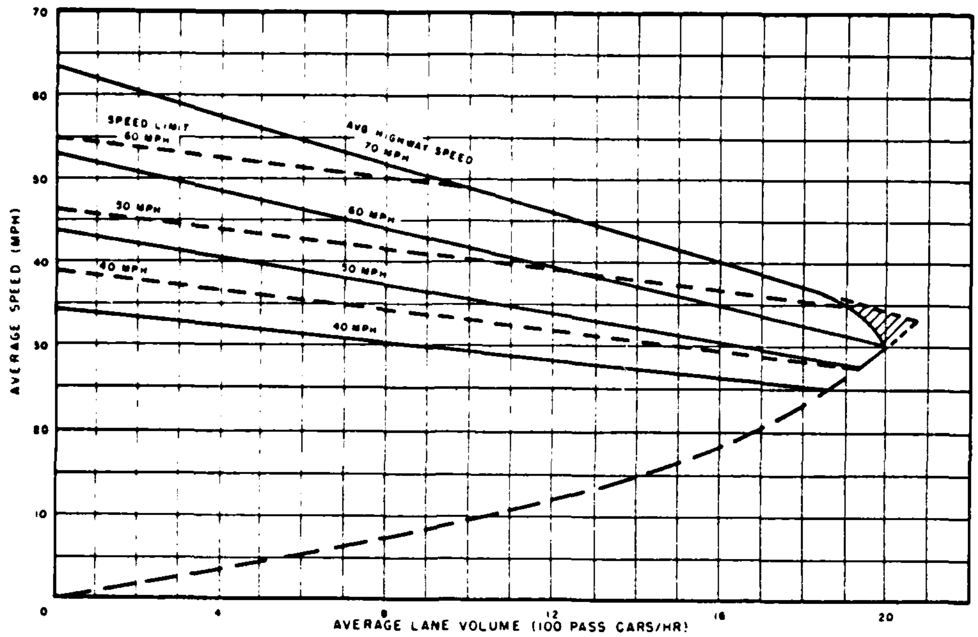

Figure 1. TYPICAL RELATIONSHIPS BETWEEN VOLUME PER LANE AND AVERAGE SPEED IN ONE DIRECTION OF TRAVEL UNDER IDEAL UNINTERRUPTED FLOW CONDITIONS ON MULTILANE RURAL HIGHWAYS

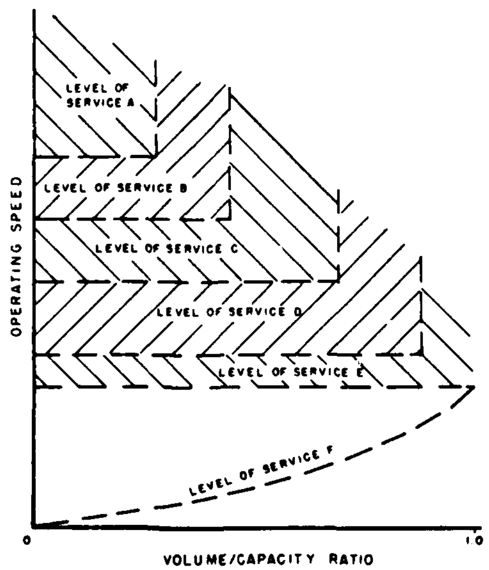

Figure 2. GENERAL CONCEPT OF RELATIONSHIP OF LEVELS OF SERVICE TO OPERATING SPEED AND VOLUME CAPACITY RADIO (Not to scale)

The Highway Capacity Manual introduces the concept of level of service to characterize various flow rates. From Reference 8: "Level of service is a qualitative measure of the effect of a number of factors, which include speed and travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and conveniences, and operating costs. In practice, selected specific levels are defined in terms of certain limiting values of certain of these factors." These levels of service are depicted conceptually in Figure 2, also from Reference 8.

For level of service A, maximum traffic flow rate on sections of freeway uninterrupted by ramps is given in Reference 8 as 700 vehicles per hour per lane[1] for 2 lanes in each direction with operating speeds of 60 miles/hour or greater. For level of service B, the volume is 1000 cars per lane per hour at a speed level of 55 miles per hour. At level C the flow is still stable and 1500 cars per lane per hour can be accommodated for short periods. Level D has a capacity of 1800 vehicles per lane per hour but potential conflict points begin to have a much greater effect on operations. Traffic may operate near capacity at these points, although at least partial freedom of movement may well remain between them. These conflict points, or potential bottlenecks, begin to meter the flow throughout entire roadway sections. Level of service E gives volume approaching ideal capacity of 2000 vehicles per lane per hour, but is an unstable flow condition. Operating speeds are 30 to 38 miles per hour. From Reference 8: "Traffic flow within the hour will,

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[1]For non-ideal freeways with limitations due to inadequate shoulders, curves and hills, etc., these volumes must be multiplied by factors due to such non-ideal conditions.

therefore, show relatively little fluctuation, inasmuch as traffic is in effect being successively metered along the highway; but still there will be variations. Until it becomes extreme this fluctuating traffic movement along the highway can be accommodated, but the public considers this to be very poor service; as actual stoppages become more frequent their effect tends to be cumulative, increasingly detrimental, and finally constant, with traffic operations reverting to forced flow conditions. This marks the division between level of service E and level of service F." At level F "volumes vary widely and speeds range from 30 miles per hour to zero." Very often, where a sudden demand surge occurs, operation may bypass level E completely, passing directly (that is "breaking down") from level D into this forced flow level F.

These levels of service are for normal freeway operation. The traffic during an evacuation will probably be degraded from this flow rate for several reasons: vehicles may be overloaded and thus have degraded operating characteristics, drivers will be operating under conditions of high stress and anxiety, and the drivers will be on unfamiliar roads. These factors will cause degradations of flow volumes, although quantification of these effects is difficult. From Reference 10: "The extent of the reduction in service volumes due to weekend traffic varies according to local conditions, and again there is little data to quantify this effect...it is recommended that the maximum service volume be reduced by 10 to 15 percent where weekend traffic is being considered. There is some evidence, particularly from California, that reductions for weekend traffic may be even larger than this." A qualitative assessment might consider evacuation traffic somewhat worse than weekend traffic and assign a reduction in volume of 25 percent.

The above capacities are for normal dry weather conditions. When inclement weather reduces driver visibility or causes slippery pavements, a reduction in capacity occurs. Reference 11 suggests a 10 percent capacity reduction in volume due to rain. Snow and ice can, in the extreme, reduce the capacity of a facility to zero. The durations of such service interruptions depend upon the level of road clearance services as well as weather conditions.

The stopping of vehicles on a freeway due to mechanical trouble, accidents, or lack of fuel could cause lane blockage and temporary flow restrictions. A bottleneck will form which will move downstream as more vehicles approach the stoppage. When the restriction is removed the traffic closest to the stoppage will begin to move. The maximum rate at which vehicles begin to move is 1600 vehicles per lane per hour [Reference 8], thus for the effect of traffic interruptions to be dissipated the approaching flow must be less than this value. If traffic stoppages are not to become excessive in length it is necessary to remove the lane blockage reasonably soon. For example, suppose one lane of two outbound lanes of a freeway carrying 1000 vehicles per lane per hour is blocked for an hour. Suppose further that traffic in the free lane passing the interruption is 500 vehicles/hour. Reference 11, p. 482, gives a rate of 1,300 vehicles/hour on a 2 lane freeway passing an incident with one lane blocked. In Reference 12, measurements on the Gulf Freeway in Houston, which has 3 lanes in each direction, gives a flow rate of 52 percent of Normal Flow Capacity for one lane blocked by a stall, 21 percent for 2 lanes blocked by an accident, and 72 percent for an accident on the shoulder. Suppose traffic can be stored upstream of the blockage at 200 vehicles per mile. Then with the assumed conditions at the time of the blockage

clearing, there would be 1500 vehicles stored in the two lanes extending upstream for three and one half miles. When the obstruction is removed traffic will begin to move at 1500 vehicles per lane per hour. While the front of the obstruction begins to be dissipated, traffic in the rear continues to arrive. The total blockage would not be cleared for another 1.4 hours at which time the head of the obstruction would be ten and one half miles upstream of the original incident. If the original blockage is cleared in ten minutes, the upstream blockage would only extend 1.75 miles.

Adequate shoulders is a requirement for rural interstate highways. Rapid clearance of lane blockages would almost always be physically possible. The major requirement is for it to be done. The prime requirement appears to be adequate control of the highway to remove the blockage. This would require either self discipline on the part of the evacuees to remove a lane blockage as soon as possible, or location and removal of the blockage as soon as possible by the proper authorities.

In later sections of this study a flow of 6000 people per interstate highway will be assumed. At an average of three people per car, this is 2000 vehicles per highway per hour. For two lanes of outbound traffic this becomes 1000 vehicles per lane per hour. For normal traffic this is service level B. For the degraded conditions of an evacuation it may be service level C, still a stable fairly high speed traffic flow. (The average number of people per household in urbanized areas is 2.75. This number of people per car would

give about 1100 vehicles per lane per hour, still a stable flow.[1])

Another source of possible freeway blockage is at exit ramps. Typically distances between exits on rural interstate highways is little less than ten miles. For an average travel distance of one hundred miles there are somewhat over ten ramps available. With the flow of 2000 vehicles per hour for the highway evenly distributed over these ramps, an exit volume of 200 vehicles per ramp per hour is obtained. This rate is well within typical ramp capacities, and within the capacity of almost any rural road system feeding the exit. The only possibility for freeway blockage which could be envisioned is due to cars stopped at the rural road intersections not knowing where to go from there. Some traffic control at the exit ramps to distribute evacuees to specific host areas appears to be called for.

A possible means of increasing freeway traffic flow is to use lanes which are normally used for inbound traffic as additional outbound traffic lanes. At least during the major surge of evacuation traffic, the additional flow capability may be much more important than maintaining an inbound traffic capability. The prime requirement for establishing such reverse flow seems to be maintaining proper control over the highway traffic. If this is done then the freeway capability for evacuation traffic could be almost doubled. These possibilities seem to make the estimate of 6000 people per hour per interstate highway very conservative.

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[1]If a substantial amount of household goods are brought along then the maximum load carrying capacity of private automobiles becomes important. Carrying more than 3 people may then lead to degraded performance due to overloading.

In order to obtain maximum use of urban freeways, and avoid the unstable flow conditions of level of service F, the metering of traffic on entrance ramps is often practiced to control the total number of vehicles on the freeway. A critical point in urban freeway flow is the merging of traffic from an entrance ramp onto the freeway. If demand for freeway entrance at ramps is sufficiently high for too long a period of time the entire freeway flow can become unstable and flow volumes can drop substantially. The prevention of this condition becomes critical for maximum traffic flow and is the reason for metering traffic at the entrance ramps.

The most critical element of traffic control in an evacuation thus appears to be the control of entrance traffic onto a freeway. One could imagine a high demand at each freeway entrance ramp over an extended period with a resultant breakdown in traffic flow conditions. To prevent this, either traffic must be restricted to enter at limited rates at all ramps, or all entrance ramps must be closed but a few which will automatically meter traffic at the appropriate level of service.

The method of metering traffic onto freeways will of course depend upon local conditions, and local available traffic control resources. The technique posited in the next paragraph is suggested both to minimize freeway traffic flow control problems and to minimize time of exposure of the urban population to direct effects. It may, however, strain local traffic control resources.

The population of the city would be evacuated by sections. One or two ramps to a particular freeway would be open for periods of possibly an hour at a time; the number of ramps would be selected to maintain the proper traffic flow feeding of the rural freeways. Sections of the city adjacent

to the open ramps would be evacuated completely at this time, with radio announcements shortly before the event telling the city population which sections were next. Traffic control into the evacuating section would be established to minimize the number of people who attempt to drive into this section to evacuate. When all the immediate evacuation traffic demand from this section is satisfied, the feeding ramps to the freeway would be closed and another section opened. At a later time, access from the original section would be reestablished to accomodate those who, for one reason or another, did not leave during the original period.

People who live in sections which are not selected at an early time may become quite impatient. One possible means to alleviate this anxiety would be to allow them to attempt to leave any time they desired over the secondary rural road network leaving the city, over which a minimum of control would be maintained. A person would thus have two choices, either to remain in the primary controlled system over the freeways, or to leave this system and attempt evacuation on his own over the unsupervised network.

The above procedure is one of a number of possiblities. One variation would be to only allow immediate access to the freeways from the central portion of the cities and force those nearer the fringe to use the secondary road system. Another would be to have the primary metering from the feeding routes to freeway ramps. The best method would probably vary from locality to locality. The basic point emphasized here is the importance of maintaining access control to the freeways and restricting the traffic flow to that level which will maintain adequate flow over the rural sections of the road.

2. Secondary Roads

The configuration of the interstate highway system is dominated by the needs of intercity travel. The nature of the roads of less than interstate quality is strongly dependent on the nature of the rural areas around an urbanized area. If the rural area is rich farmland, a well developed secondary road system will be found. If the rural area is mountainous or desert, only a minimal network will be found. Natural barriers such as rivers may interrupt the secondary road system and prevent any travel across the barrier except on an arterial highway. Each urbanized area presents its own features.

Before the construction of the interstate system, the U.S. federal highways provided a network linking cities. In many areas this network remains in place and supplements the freeway network with a second network of comparable capacity. In other areas the interstate roads have replaced the federal roads by generally following the same routes. This has occurred more often either where terrain limits route selection or where a small local rural population density does away with the need for maintaining the federal roads.

The density of secondary roads is correlated with the local rural population density. In areas where the local rural population density surrounding a city is high, reception areas can support a large evacuated population. Fortunately these are areas where a more extensive secondary road network is present. Here the interstate system can be reserved for those evacuees from a city who will be located at further distances; the secondary roads would be adequate to transport those evacuees who will be located near the city.

A difficult situation occurs when the rural area surrounding a city has low population density but the population increases at further distances where reception areas would be located. Here there is a poor secondary road network, and all the traffic flow must be over the primary network. Probably an outstanding example of this problem is Los Angeles. In addition to being located in a desert area there is a mountain barrier running north of the city. Major reception areas for Los Angeles are located in the valley to the Northeast of the city. The combination of mountains and desert forces almost all the traffic flow onto the interstate road network, with almost no local traffic flow.

The other extreme of this situation for a large city is Chicago. The adjacent farmland is densely populated, and numerous secondary arterial highways lead from the city. In addition, a system of farm roads provides a grid of usable roads with one mile spacing. Lake Michigan, of course, prevents flow in one direction, but this extensive secondary grid is in the other direction. The only natural barrier to this flow is the Fox River, but an extensive series of bridges, which are part of the secondary road system, should prevent this from being a serious obstacle.

Chapter III

DESCRIPTION OF THE MODEL

A. INTRODUCTION

This chapter will describe a model developed to yield estimates of the rate at which people would leave risk areas. It assumes that none has left a risk area until a starting time, and then suddenly everyone in the risk area wishes to leave. The evacuation is assumed to occur entirely by private automobile, primarily over the interstate highway network. The primary limitation on the rate of evacuation is the highway system leaving the risk areas. The capacity of this highway system is the subject of the model.

In many scenarios the perception of a threat of nuclear attack gradually develops. As this perception grows, people gradually begin to leave risk areas. The demand on highways is spread over a longer time and the highway capacity is less of a limiting factor. The present assumptions therefore are a limiting case since they assume all demand is generated at once, which would maximize highway congestion.

B. EVACUATING CENTER

The population data are based on the 1970 census. The areas at risk are the 247 urbanized areas of the census. The total population at risk is 123.7 million people of a total United States population in the data base of 212.0 million.

FEMA has identified some 320 conglomerate risk areas. Some 80 of these are not urbanized areas (FEMA has several conglomerate risk areas made up of more than one urbanized

area). The population in the risk areas which are not urbanized areas is about five percent of the total population at risk. Restricting this analysis to only urbanized areas does not significantly affect the overall results. Of course such risk areas would be considered in more detailed planning.

C. ROAD NETWORK

The road network used to carry traffic from a city is primarily the interstate highway system. Added to these roads are a few other main arterial roads of at least interstate quality, but not explicitly a part of the interstate system. The roads were obtained from a nationwide road map. For each risk area, the highways leading from the city were identified by route number, a code number for the next risk area along the road, and the distance between the risk areas.

D. RECEPTION CAPACITY FOR EACH ROAD LINK

In order to guard against computing road flows which could lead to unrealistic placement of evacuees, a method was developed to limit the number of evacuees who could be put in areas adjacent to the evacuation highways. To do this the urbanized area and rural population for each state were determined, and the urban to rural ratio of population computed, as shown in Table 1. This ratio was multiplied by an input factor, called here the excess factor, to yield a packing factor which was applied to the entire state. This excess factor was chosen to account for non-uniform distributions of rural population in a state, which would require higher ratios of evacuees to local population to achieve reasonable distributions of traffic along the evacuation routes. A value of 1.5 for this excess factor was used in the calculation presented here for every state, and

Table 1. RECEPTION POTENTIAL BY STATE

FIPS Code	State Name	Urban Population	Urban/Rural Ratio	Packing Factor	Rural Density (People/Mile^2)	Fraction of Area Used
1 01	Ala.	1317788.	.7991	1.1987	32.53	1
2 04	Ariz.	1215418.	2.7813	4.1719	9.64	.4
3 05	Ark.	374789.	.3317	.4975	21.76	1
4 06	Calif.	16957528.	7.2936	10.9403	24.79	.6
5 08	Colo.	1495212.	2.6558	3.9837	7.76	.7
6 09	Conn.	2143775.	2.7240	4.0860	161.95	1
7 10	Del.	389831.	2.2931	3.4397	85.81	1
8 11	D.C.	2604669.	.9383	1.4075	47.19	1
9 12	Fla.	4339949.	2.5620	3.8429	39.16	.8
10 13	Ga.	1984752.	.9189	1.3783	37.19	1
11 16	Ida.	89446.	.2130	.3194	10.18	.5
12 17	Ill.	8622166.	3.7374	5.6061	41.39	1
13 18	Ind.	1898205.	.9022	1.3533	58.31	1
14 19	Ia.	693596.	.4833	.7250	25.66	1
15 20	Kans.	456164.	.4772	.7157	14.62	.8
16 21	Ky.	999183.	.5733	.8599	43.98	1
17 22	La.	1788281.	1.2282	1.8423	36.01	.9
18 23	Me.	180402.	.3058	.4586	38.20	.5
19 24	Md.	1656079.	1.6429	2.4644	101.99	1
20 25	Mass.	4576538.	4.3013	6 4519	135.99	1
21 26	Mich.	5902742.	2.1935	3.2903	59.20	.8
22 27	Minn.	1987061.	1.3247	1.9871	23.65	.8
23 28	Miss.	327244.	.2319	.3479	29.85	1
24 29	Mo.	3398576.	2.0685	3.1028	23.82	1
25 30	Mont.	149207.	.3758	.5638	9.10	.3
26 31	Nebr.	677479.	1.0296	1.5444	12.30	.7
27 32	Nev.	353186.	3.1255	4.6883	2.57	.4
28 33	N.H.	162669.	.4457	.6685	40.50	1
29 34	N.J.	503947.	.5396	.8093	124.19	1
30 35	N. Mex.	312324.	.8219	1.2329	6.27	.5
31 36	N.Y.	20057030.	6.4080	9.6120	65.46	1
32 37	N.C.	1271078.	.4034	.6051	71.76	.9
33 38	N. Dak.	89718.	.2425	.3637	5.94	.9
34 39	Ohio	7008907	2.3324	3.4986	73.35	1
35 40	Okla.	1098769.	1.1132	1.6699	14.36	1
36 41	Ore.	1110084.	1.3358	2.0038	28.80	.3
37 42	Penna.	8041867.	2.0395	3.0593	9.75	.9
38 44	R.I.	835039	6.0952	9.1428	131.05	1
39 45	S.C.	658616.	.4203	.6305	51.84	1
40 46	S. Dak.	78903.	.1806	.2708	9.61	.6
41 47	Tenn.	1602828.	.8730	1.3095	49.36	.9
42 48	Tex.	7285103.	2.5724	3.8586	13.51	.8
43 49	Utah	769838.	2.9609	4.4414	10.56	.3
44 50	Vt.	0.	.0000	.0000	36.01	1
45 51	Va.	1761231.	.9383	1.4075	47.19	1
46 53	Wash.	1890261.	1.7122	2.5683	33.17	.5
47 54	W. Va.	437602.	.3665	.5498	49.64	1
48 55	Wis.	2138863.	1.2173	1.8260	40.33	.8
49 56	Wyo.	0.	.0000	.0000	3.59	.5

the resulting packing factors are shown in Table 1. The density of rural population in each state (in people per square mile) was computed by dividing the rural population of a state by a fraction of the state area. This fraction was that portion of the state that contained a substantial rural population. These fractions are shown in Table 1, along with the resulting rural density.[1] The number of evacuees which could be located along each square mile of a highway is given by the packing factor times this rural density.

The area along each road which could receive evacuees was taken as the sum of two areas, a pie shaped area radiating from the city center plus a rectangular area farther out with the highway running along the center. The angle of the pie shaped area was 360 degrees divided by the number of roads leading from the city. The pie shaped area was extended until it merged with the rectangle. The width of the rectangle was an input parameter. In the primary calculations shown here the distance from the highway to the edge of the rectangle was 20 miles, i.e., the rectangle was 40 miles wide. The rectangle extended half of the distance from the evacuating city to the next city along the highway. In cases where the distance to the next city was excessive (say, more than 400 miles), the area available was generally extended until the road left the state.

An area near the evacuating city was excluded from the area which could receive evacuees. The urban area data base contained standard deviations of the population distribution

[1]The census distinguishes between urbanized area population, basically in cities over 50,000, urban population in cities between 5,000 and 50,000 population and rural population. Only rural population is shown in Table 1. Nationwide the rural population is 63 million, and the urban population not included is 26 million.

about the centroid along two principal axes, computed from census data. The distance excluded was twice the geometric mean of these standard deviations plus six miles. The first term gives an equivalent city radius including most of the city population. The second term adds a distance for the nearby effect of nuclear weapons to be mitigated. This radius was excluded from the pie shaped plus rectangular area along each highway in computing the area available to it. The capacity of each highway to receive evacuees was finally the rural density times the adjusted packing factor times the area allocated to that highway.

It was assumed that any traffic from one evacuating city could not pass through a second evacuating city until that city was fully evacuated. However, once the second city was fully evacuated, the unused capacity of the roads from that city were assumed to be available to the first city. There were some 96 places where a second city was considered as blocking a first city and where full evacuation of the second city added to the capacity of the road between these two cities. The input data base defined these claimed cities and the program increased the appropriate road capacities as the cities were evacuated.

E. EVACUATION FLOW RATES

The number of people per hour evacuating over each road was taken as an input nominal flow value modified by certain local conditions. The nominal flow value used here was 6,000 people per hour for each road.

The number of people per hour on each road could be considered as the product of people per vehicle times the number of vehicles per hour per road lane times the number of lanes per road. One way to obtain the value of 6,000 people

per hour is to take the number of people per vehicle as 3, the number of cars per lane per hour as 1,000, and the number of lanes per road as 2, as discussed in the previous chapter.[1]

For certain critical road links (e.g. the New York Thruway between New York City and Albany) the road capacity was increased by a factor of from 2 to 4 either because of additional lanes in the interstate link or additional interstate links connecting the cities. Seven such links were defined between the following evacuating centers: New York to Albany, Dallas to Fort Worth, Chicago to Elgin, Miami to Fort Lauderdale, San Francisco to San Jose, Los Angeles to San Bernadino and Boston to Worcester. As is evident, in most cases these links are between urbanized areas existing in a larger congested area.

The nominal road flow rate for each city was modified by two qualitative factors, a terrain factor and a congestion factor. The terrain factor was estimated from maps on a scale of from 1 to 5. The terrain description for each factor of the evacuating cities in each category and modifying factor is given in the following table. The nominal flow rate was multiplied by the terrain factor.

Category	Description	Percent in Categories	Terrain Factor
1	Flat	53	1.02
2	Slightly Rolling	20	1.00
3	Hilly	17	.95
4	Somewhat Steep	8	.90
5	Mountainous	2	.70

[1]As a rough approximation, the times required to evacuate are inversely proportional to the nominal flow rate. Thus if the planned rate is increased by multiplying some factor, the evacuation times would be decreased dividing by this same factor.

The road flow rates for each evacuating area were assumed to be decreased if it were in a region of general congestion where smooth traffic flow along the evacuating network would be blocked. The nominal flow rate was decreased by an amount calculated using an estimated congestion index. The following table defines the index, shows the percentage of cities associated with each value and gives the decrease of the nominal value applied to each road leaving the city.

Category	Congestion Description	Percent in Category	Decrease in Nominal Rate People/Hour
1	None	7	0
2	Some	31	100
3	Small Blocking	27	200
4	Almost Blocked	26	300
5	Blocked	9	400

It was assumed that in addition to the interstate network, some people would leave over a local network of other roads leading from each urbanized area. The number of people per hour leaving over this local network would be given by an estimated number of people per hour per mile along the perimeter of the city times the city perimeter. The city perimeter was calculated using twice the geometric mean of the standard deviations of the city population about the population centroid used for computing exclusion areas. The flow rate index was based on a local rural road density index estimated from road maps of the area surrounding the urbanized area. The following table gives the value of this flow index for different road density categories, and the percent of cities in each category.

Category	Percent of Cities in Category	Flow Rate People Per Hour Per Mile
1	3	30
2	17	60
3	36	100
4	33	200
5	11	400

As an example of how this index might be estimated, suppose that every five miles along the perimeter of a city there is a two lane road, traffic is constrained to only the outbound lanes of these roads at a flow rate of 300 cars/hour, and there are three people per car. Then a flow rate of 180 (300x3÷5) people per hour per mile of perimeter would be calculated and an index of 4 assigned. In the basic calculation about one-fourth of the total nationwide flow road capacity was over secondary roads.

F. CALCULATION PROCEDURE

A program to calculate evacuation rates was implemented on the FEMA 1108 computer. The calculation procedure was straightforward. The program first read control parameters, then the city data base, and finally the road data base on terrain, congestion, local road and blocking parameters. The program computed allowable rural densities by state, and capacities and flow rates for each road.

The program computed evacuation conditions in increments of one hour. At the end of each hour the evacuating city population was decremented by the sum of the road flows, and the residual road capacity decremented by the flow along that road. When a city was completely evacuated, a check was made to see if it was a blocking city. If so, its residual road capacity was added to that road leading to the city it blocked.

Printing options allow the printing of nationwide summaries of the results of unblocking roads as the evacuation progresses and a summary for each evacuating center at the end of the run. Detailed histories of the condition of selected evacuating centers during the calculation may also be obtained. The calculation only takes a short time to compute on the FEMA 1108 computer.

PREFACE

The research for this report was conducted by the Institute for Defense Analyses (IDA) for the Federal Emergency Management Agency (FEMA) under Contract EMW-C-0749, Work Unit 4112C, dated September 1981.

An objective of the research was to estimate the cost in survivors of short warning leading to attack during full nationwide crisis relocation. A simulation model of traffic flow over the national interstate road network was developed to predict population vulnerability during a crisis relocation. The model predicts large initial rates of reduction in nationwide vulnerability (half the at-risk population is evacuated in 21 hours) due to the large number of risk centers initially evacuating. Problems arising in risk areas, reception areas, and over the road network to achieve the traffic plan assumptions of the model are discussed. No unreasonable problems are uncovered in achieving the major prediction of the model.

This publication is issued in partial fulfillment of the contract.

Chapter IV

RESULTS OF CALCULATIONS

A. NATIONAL RESULTS - BASE CASE

The number of people remaining in evacuation centers as a function of time after the start of an evacuation is shown in Figure 3. These calculations are for the conditions described in the previous chapter. After 12 hours, 63 percent of the original population of 123.7 million people remain in the evacuation centers; after one day, 47 percent remain; after two days, 31 percent remain; and after three days, 24 percent. At the start the number of people remaining is rapidly decreasing, but as time passes the remaining people leave at a slower and slower rate. Figure 4 presents the evacuation rate as a function of time; it shows that the evacuation rate does in fact initially decrease rapidly for about the first half day, followed by slower rates of decrease.

In this model the initial decrease in evacuation rate could be attributed to two factors, a decrease in the number of cities evacuating as smaller cities empty, and a clogging of roads as the reception areas serving them become full. Figure 5 presents the number of cities yet to be evacuated as a function of time. As can be seen this number of cities is roughly proportional to the evacuation rate and could explain

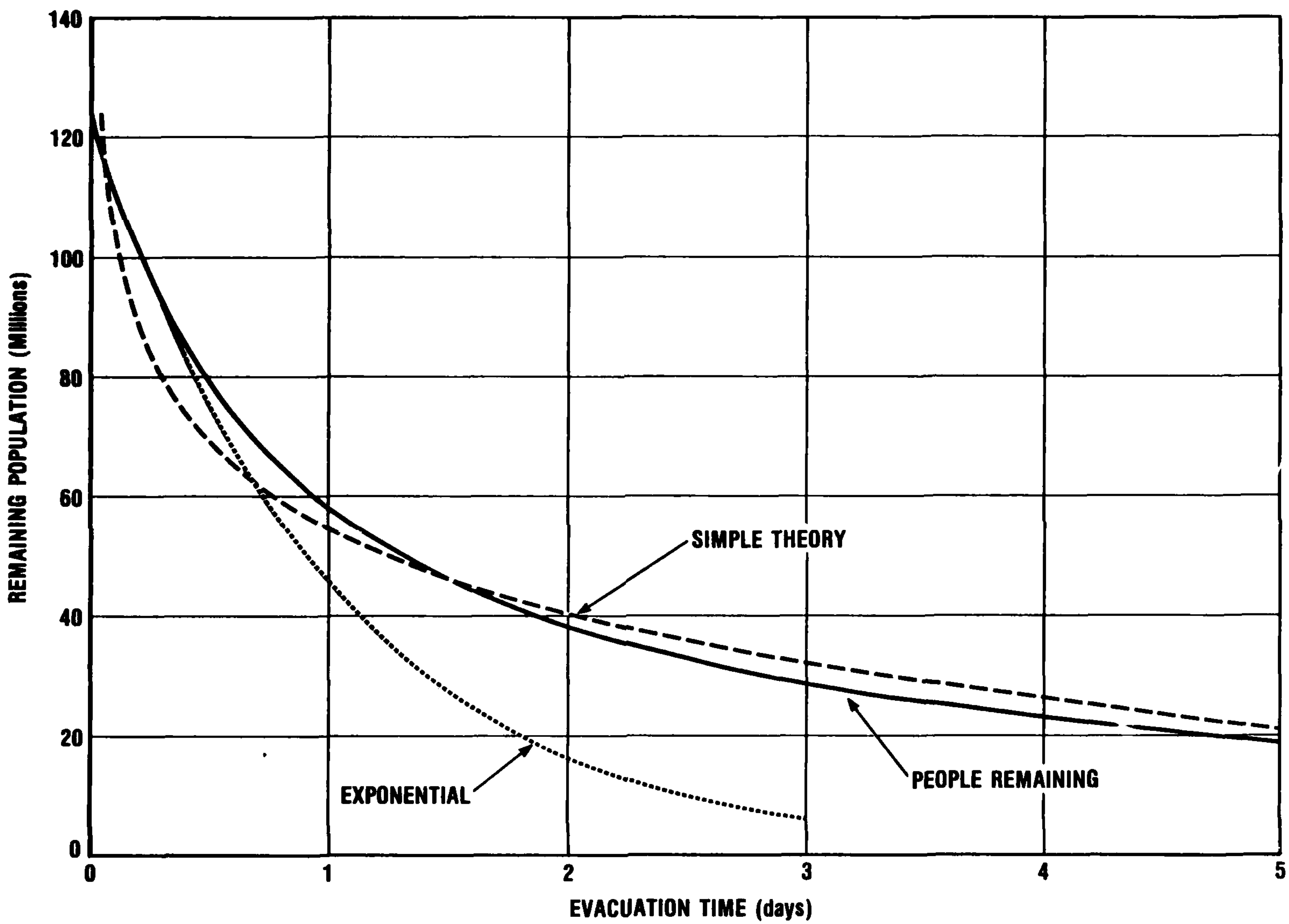

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Figure 3. PEOPLE REMAINING IN EVACUATION CENTERS AS A FUNCTION OF EVACUATION TIME

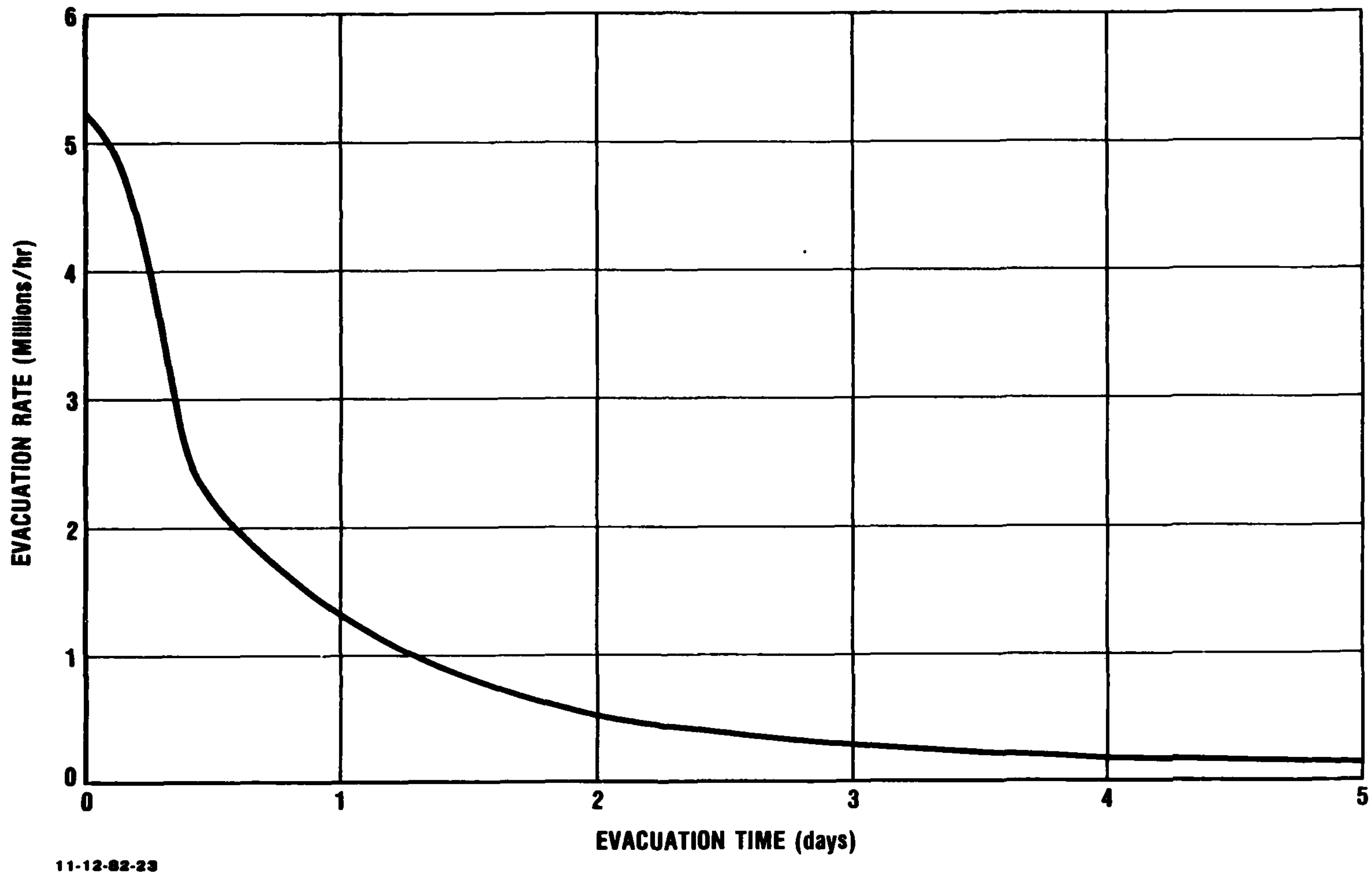

Figure 4. RATE OF EVACUATION AS A FUNCTION OF EVACUATION TIME

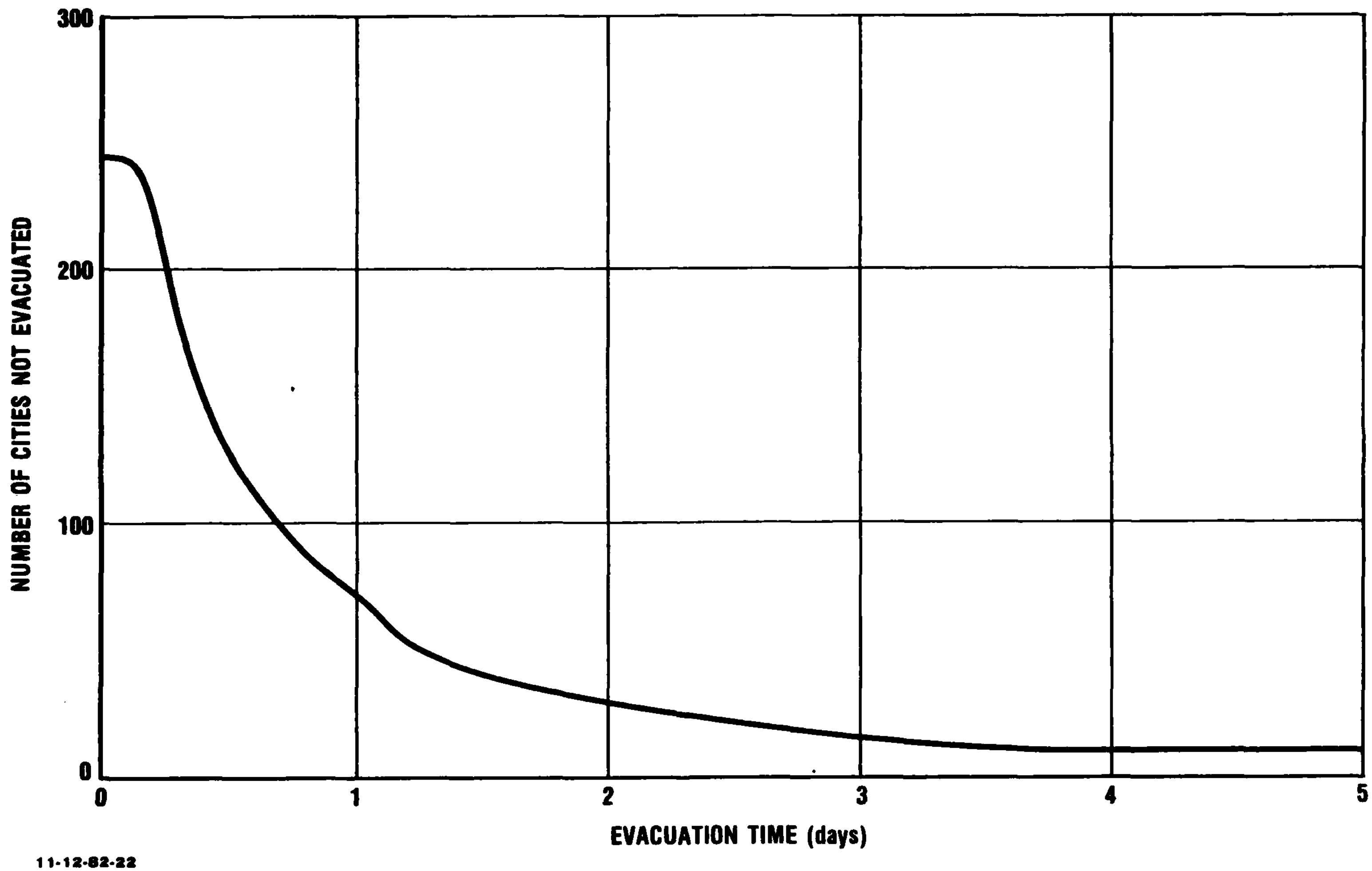

Figure 5. NUMBER OF CITIES REMAINING TO BE EVACUATED AS A FUNCTION OF EVACUATION TIME

the decreases in evacuation rates.[1] No direct calculation of road clogging was outputted.

The shape of the curve of the number of people remaining in Figure 3 appears to be roughly exponential. For comparison, an exponential curve is shown on Figure 3. The initial slope of the exponential curve is the same as the initial slope of the curve of people remaining. For the initial time the curves do roughly compare, but the exponential curve drops more rapidly than the actual curve and after about a day does not give a good approximation.

A very simple model can give a better approximation of the population not evacuated as a function of time. Assume that people leave each city that is still evacuating at a rate of α people per city per hour. Assume further that the initial population of the i^{th} evacuating city, when the cities are ranked in order of decreasing population, is given by a constant, A, divided by i (see Reference [2]). In other words

$$p_i\ (0) = \frac{A}{i}$$

where $p_i(t)$ is the population of the i^{th} city at time t after the start of the evacuation. Since people are assumed to leave each city at a constant rate, the smallest cities will be evacuated first. Suppose at time t the first n cities are not evacuated. Then

[1]The smaller cities which tend to be evacuated first tend to have a smaller number of evacuation routes. Thus the overall evacuation rate should not be expected to be directly proportional to the number of cities still evacuating people.

$$p_i(t) = \frac{A}{i} - \alpha t, \quad i \leq n \; .$$

Call the total population not evacuated p(t).

Then

$$p(t) = \sum_{i=1}^{n} \left(\frac{A}{i} - \alpha t\right) = A \sum_{i=1}^{n} \left(\frac{1}{i}\right) - n\alpha t \; .$$

Now, for appreciable n, the sum may be approximated by

$$\sum_{i=1}^{n} \frac{1}{i} \simeq \int_{1}^{n} \frac{di}{i} = \ln n \; .$$

(Reference [2]).

Thus

$$p(t) \simeq A \ln n - n\alpha t \; .$$

Now by definition the population of the n^{th} city at time t will just have decreased to zero, i.e,

$$p_n(t) = \frac{A}{n} - \alpha t = 0 \quad .$$

Solving for n

$$n = \frac{A}{\alpha t} \; ,$$

and substituting in the expression for p(t)

$$p(t) \simeq A \ln \frac{A}{\alpha t} - \frac{A}{\alpha t} \quad \alpha t$$

or

$$p(t) \simeq A \left[\ln \left(\frac{A}{\alpha t} \right) - 1 \right] \quad .$$

This is the desired approximating expression. The following scheme was used to estimate A and α . At a time of one hour the computer model gave an evacuation rate of 5.1 million people per hour, and 247 cities were being evacuated. Thus α could be estimated by setting $\alpha n_0 = 5.1$, giving $\alpha = 0.02092$. Then by trial and error a value of A equals 20.2 was found to give the desired population of 118.5 million at one hour. Since 20.2/0.02092 = 965.58, the resulting approximating curve is

$$p(t) = 20.2 \left(\ln \left(\frac{965.58}{t} \right) - 1 \right) \quad .$$

This is given as the dash dot curve in Figure 3 and lies surprisingly close to the curve predicted by the model. At late times the population is overestimated by about ten percent, and at early times it is underestimated by a maximum of about 15 percent.

B. TYPICAL LOCAL RESULTS BASE CASE

The first state in an alphabetical list, Alabama, will be used as an example of the evacuation process for an area where there is no special congestion. According to the 1970 census, there were six urbanized areas to be used as evacuation centers. Table 2 lists some properties of these areas, the time required to complete evacuation, the road flow rate from each city, and the total local flow over the secondary road system.

Table 2. PROPERTIES OF EVACUATING NODES IN ALABAMA

No.	Name	Population	Local Road Index	Congestion Index	Terrain Index	Time to Complete Evacuation (Hours)	Road Flow Rate People/Road/Hr	Total Local Flow People/Hr
1	Gadsen	71803	4	2	3	3	5600	5915
2	Birmingham	586004	3	2	3	25	5600	5952
3	Huntsville	153893	4	2	2	6	5900	7146
4	Mobile	270707	2	3	1	18	5920	2422
5	Montgomery	145932	4	2	2	5	5900	4997
6	Tuscaloosa	90169	4	2	2	6	5900	4652

Table 3 describes the roads used for each evacuating node. The I in the highway route number column denotes an interstate highway, a U denotes a four lane federal highway. If the road connects two evacuating centers, indicated by the absence of a star in the destination column, the distance is one-half the distance between the two centers. If there is a star in the destination column, the destination identifies the direction the road travels, and the distance is that deemed appropriate to assign it this road segment. The capacity is the original reception center capacity of the road. A road map of Alabama would help in reading this table.

The cities of Gadsen and Tuscaloosa were judged to interfere with the traffic on Interstate 20 in both directions from Birmingham and were defined as blocking cities. When their evacuation was completed, their unused reception center capacity was given to Birmingham.

A time history of the population in each of the six evacuation centers in Alabama is shown in Figure 6. The numbered arrows on the figure refer to times when either routes were closed to further evacuation traffic since the reception center capacity was filled, or when additional capacity was made available. A definition of these events is given in Table 4.

Table 3. PROPERTIES OF ROAD NETWORK IN ALABAMA

No.	Name	Highway Route No.	Destination	Distance Assigned Mile	Reception Capacity
1	Gadsen				
		I59	Birmingham	30	36510
		I59	Chattanoga, Tenn.	43	65759
		U431	Huntsville*	30	36510
		U431	Anniston*	20	13111
2	Birmingham				
		I59	Gadsen	30	24838[1]
		I20	Tuscaloosa	25	14172[2]
		I20	Atlanta, Ga.	70	118435
		I65	Huntsville	40	48237
		I65	Montgomery	45	59937
3	Huntsville				
		I65	Birmingham	40	58901
		I65	Nashville, Tenn.	55	94001
		U72	Gadsen*	40	58901
		U72	Florence*	50	82301
4	Mobile				
		I10	Biloxi, Miss.	30	34684
		I10	Pensacola, Fla.	30	34684
		I65	Montgomery	90	175080
		U43	Jackson*	40	58083
5	Montgomery				
		I65	Mobile	90	170376
		I65	Birmingham	45	65079
		I85	Atlanta	75	135277
		U80	Selma*	50	76778
		U231	Dothan*	130	263974
6	Tuscaloosa				
		I20	Birmingham	25	35796
		I20	Jackson, Miss.	85	176192

[1]Increased by 74651 to 99489 after two hours when Gadsen completes its evacuation and releases unused capacity to Birmingham.

[2]Increased by 142420 to 156592 after six hours when Tuscaloosa completes its evacuation and releases unused capacity to Birmingham.

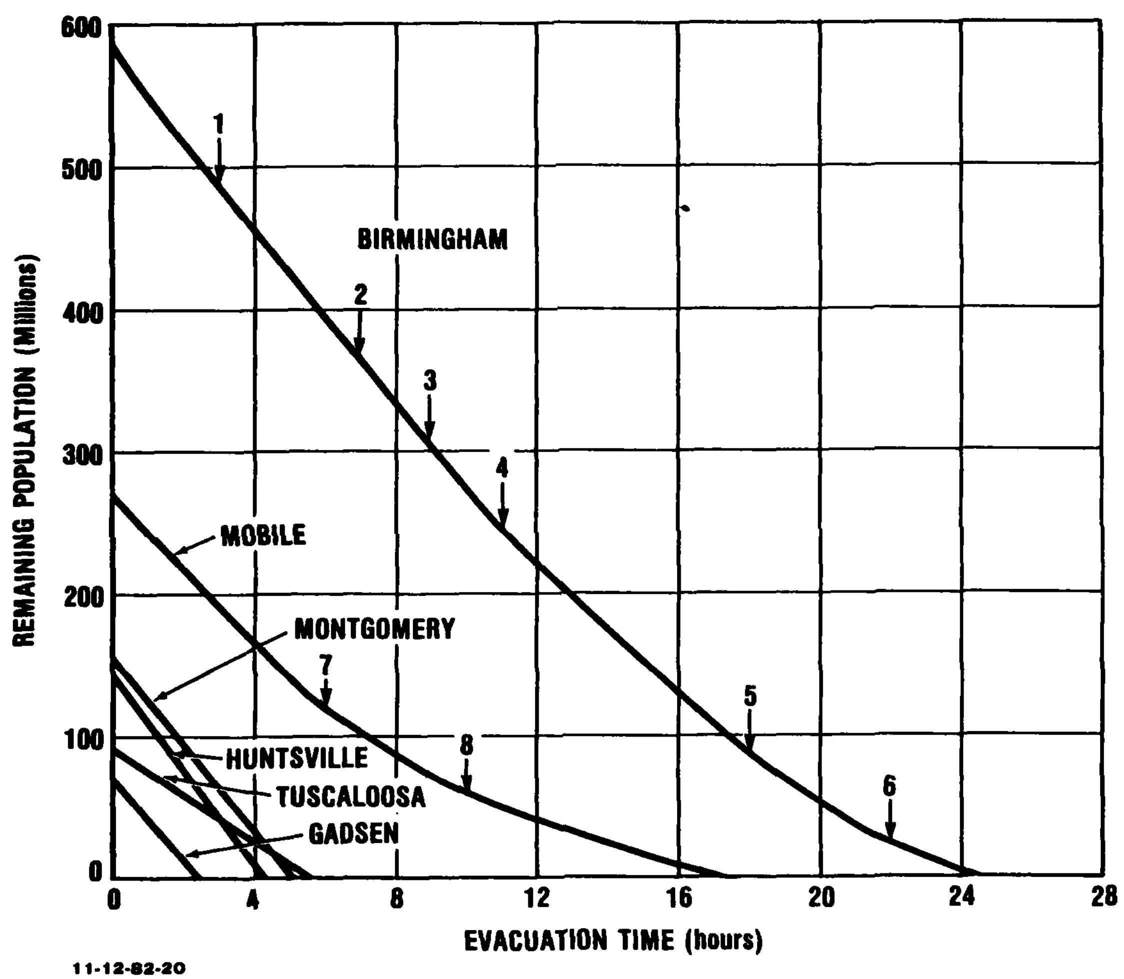

Figure 6. POPULATION REMAINING IN INDIVIDUAL EVACUATION CENTERS IN ALABAMA AS A FUNCTION OF EVACUATION TIME

Table 4. EVACUATION EVENTS

Birmingham

1. Capacity of I59 to Gadsen increased to 99489 by the complete evacuation of Gadsen. I20 to Tuscaloosa filled.
2. Capacity of I20 to Tuscaloosa increased to 156592 by the complete evacuation of Tuscaloosa. The route is reopened for evacuation traffic.
3. I65 to Huntsville filled.
4. I65 to Montgomery filled.
5. I59 to Gadsen filled.
6. I20 to Atlanta, Ga. filled.

Mobile

7. I10 to Biloxi, Miss. filled. I10 to Pensacola, Fla. filled.
8. U43 to Jackson filled.

The flow from the four smallest evacuation centers in Alabama proceeded with all routes used without interruption. The evacuation lines of Birmingham and Mobile were extended, however, for about seven hours due to the filling of some evacuation routes.

The estimates of evacuation time produced by the model for Alabama appear as direct results of a calculation with simple assumptions. An actual evacuation scheme would more carefully allocate reception centers and routes, particularly to Birmingham and Mobile. The traffic pattern near Mobile might deserve careful attention due to the proximity of Mobile Bay. However, the basic traffic patterns required in an actual plan appear basically simple and susceptible to direct analysis.

C. CONGESTED AREAS - BASE CASE

In direct contrast to the calculations for the less congested areas are the calculations for larger areas where road flow is constricting and where congestion from competing evacuation centers is severe. In these areas it appears that this model does not allocate the traffic carefully enough to make reasonable predictions except for the initial period of about one day when road congestion is not yet too severe. This analysis, nevertheless, is probably detailed enough to indicate which are the areas requiring special attention.

A nominal evacuation goal of three days has often been used by FEMA. Table 5 lists those evacuating centers where an evacuation time of more than three days was predicted, along with the population to be evacuated, initial flow along the identified evacuation routes, calculated evacuation time obtained by dividing initial population by initial road flow rate, and evacuation time predicted by the model. The ratio of these latter two values could be taken as an index of the difficulties encountered by an evacuation center from nearby evacuation centers.

Table 5. CENTERS REQUIRING MORE THAN THREE DAYS TO EVACUATE

Evacuation Center	Original Population	Initial Flow Rate (People/Hr.)	Population/ Flow Rate (Hours)	Model Evacuation Time (Hours)
San Francisco, Calif.	3137240	25,000	125	173
Los Angeles, Calif.	8768829	25,000	350	>1000
Monterey, Calif.	97948	3,800	26	123
San Diego, Calif.	1258239	10,600	119	75
San Jose, Calif.	1076536	10,800	100	118
Washington, D.C.	2604669	34,800	75	122
Miami, Fla.	1280644	17,160	75	140
Chicago, Ill.	7049550	69,840	101	84
Detroit, Mich.	4167119	29,100	143	119
Minneapolis, Minn.	1782357	42,140	42	74
Omaha, Nebra.	516364	24,080	21	77
New York, N.Y.	17014224	48,760	349	304
Pittsburgh, Pa.	1937929	30600	63	162
Altoona, Pa.	85885	0	-	77
Philadelphia, Pa.	4221889	28,000	151	160
Brownsville, Texas	55258	0	-	72

At this point it is tempting to digress into a discussion concerning each entry on this list of troublesome centers, but since this digression would illustrate nothing more than the authors knowledge (or ignorance) of local geography, only the following remarks will be given.

1. The absence of large Texas cities in the table might be surprising. The following additions are given:

Dallas, Texas	1405619	52,380	27	58
Houston, Texas	1761756	34,920	50	60

   In each case, the major roads leading from the city yield sufficiently low evacuation times based on initial flow rates. That congestion which does occur does not raise the total evacuation time to over the critical level.

2. The presence of Monterey, California on this list is at first surprising. However, the only major road from Monterey leads to Salinas, which in turn is blocked by San Francisco traffic. Moreover, the local road index is one, since the mountainous terrain near Monterey minimizes evacuation traffic of this type.

3. The evacuation time for Chicago based upon the ratio of initial population to initial flow rate is 101 hours, while the model predicted 84 hours. This implies an appreciable contribution from traffic over local roads. Since the author is a native of Chicago, I will claim, in this case, a good knowledge of local geography and traffic patterns. I recall many holiday weekends where the best way of leaving or entering the city was to give up on the congested main roads and have recourse to the extensive secondary road network. (Recalling that this is originally in the Northwest Territory, even a tertiary road network is available.) Since I do not recall being noticeably more astute that my co-citizens in these matters, I feel that this network would be used to advantage. In view of the density of this network, and the large perimeter of the city as it is wrapped around Lake Michigan, such predictions do not seem amiss.

D. PARAMETER EXCURSION

Two parametric excursions are shown in Figure 7. In the first, the limitations on reception center capacity are removed. This results in about a 15 percent reduction in evacuation time. The upper curves present one variation where the reception potential and load flow rates are reduced to one-half the base case values and another where local road network flows are reduced to zero. Here a dramatic effect on evacuation capacity is seen.

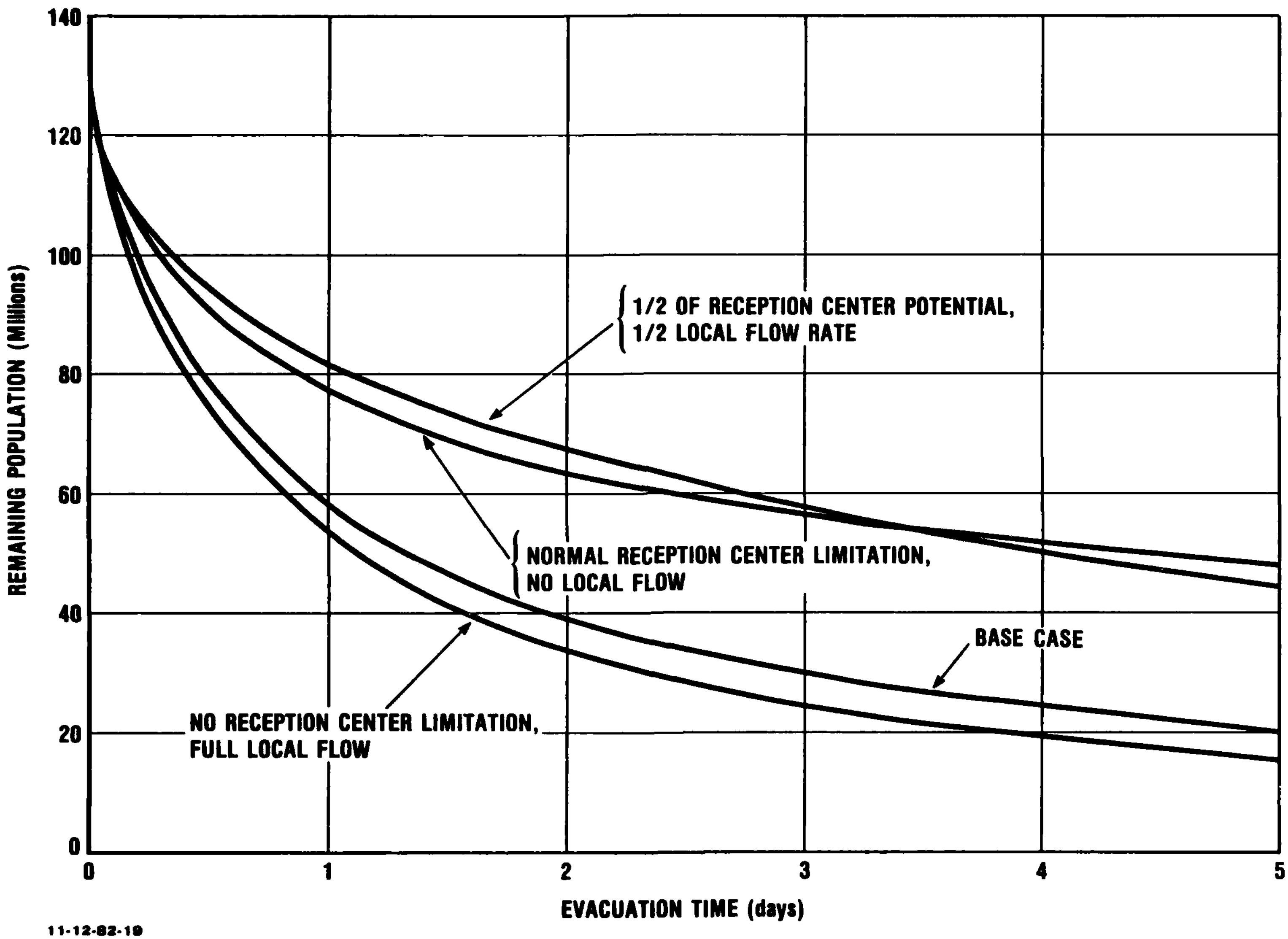

Figure 7. EFFECT OF RECEPTION CENTER LIMITATION AND LOCAL FLOW RATES ON EVACUATION TIMES

Chapter V

CONCLUSIONS

At the start of nationwide evacuation there is an immediate rapid decrease in the vulnerability of the population to an attack by nuclear weapons. As the evacuation continues, this reduction in vulnerability continues, but in terms of people saved per hour, at an ever decreasing rate. For a few major evacuation centers, the reduction in vulnerability near the start of an evacuation is problematical because the loss of vulnerability of the relatively small percent of those who have left must be compared to the possible increase in vulnerability of those waiting to be evacuated. However, in nationwide terms this problem of a few cities is overwhelmed by the large number of people who are rapidly evacuated from many moderate-sized evacuation centers. Thus while an evacuation might increase the vulnerability of some people at certain times, for the majority of the people evacuation reduces vulnerability.

The following paragraphs further summarize implications from this paper.

1. The basic answer to the question of vulnerability change at the start of an evacuation is simple. At early times many centers are sending evacuees over an unclogged road network. An initial nationwide evacuation rate can be estimated by assuming 6000 people per hour leaving over each of four roads per evacuation center for 250 centers to give a rate of 6,000,000 people per hour. This is near the model estimate. Until most of the small centers are evacuated, the

flow of people from them completely dominates congestion problems from larger centers.

2. For later times and the congested situations near large urban centers, the results of the model are certainly questionable. About 10 to 20 percent of the initial at-risk population is involved in this uncertainty. A more detailed analysis is needed to give better answers in these situations.

3. The basic transportation mode considered in this study is by private automobile over the primary intercity arterial highway network. The capacity of this mode is adequate to yield the basic crisis relocation capability.

- The scenario considered is a worst case scenario in the sense of maximizing the bottleneck effects of the highway network. Of course a scenario with sufficiently inclement weather can yield arbitrarily low estimates of capacity.
- Auxiliary transportation modes (bus, rail, air) can provide additional transportation of special value to those without private automobiles available, but the total capability is much less than that of private automobile.
- The conversion of normally inbound road lanes to outbound lanes can result in substantial increases in peak flow capacity.
- Adequate traffic control can substantially aid in effective highway use. Of particular importance in the risk areas is control of ramp access to the freeways.

4. An appropriate criterion for the success of an evacuation effort is the number of people remaining in a risk center as a function of time. At the heart of this statement is the implicit assumption that those remaining in risk centers are at grave risk in the event of an enemy attack. While the exact nature of a future enemy attack is unknowable, the nature of an attack to optimize certain hypothetical enemy objectives can be calculated. Such calculations very often

lead to predictions of heavy attacks upon urban centers. To put it another way--if a target is attacked, it will be attacked with enough weapons to destroy most of the target with a high degree of confidence. Such hypothesized allocations of enemy weaponry imply that even if civilians are not directly attacked, their colocation with industrial targets places them at high risk. The increase in safety by not joining in evacuation is not large, and certainly not sufficient to negate the value of evacuation.

5. The question of vulnerability to fallout has been sidestepped. This question introduces the companion question of the availability of fallout shelter. Some evacuees will be fortunate enough to discover available (but not necessarily desirable) fallout shelter immediately; some evacuees will join with local construction activities to produce expedient shelters; some will produce their own shelter; and some will find no shelter. An analysis of the final produced shelters should not only consider the resources available, but also the motivation of those who use these resources. Since both are beyond the intent of this study, a categorization of fallout vulnerability is not presented here.

The time for an evacuee to enter into fallout protection can be taken as the sum of two times, the time between leaving an evacuation center and arriving at a reception center, and the time between entering a reception center and entering fallout protection. The average travel distance calculated in this model may be 150 miles (Reference 9 gives 250 miles). At the flow rates assumed for the interstate highways, a vehicle speed of 35 mph would be conservative. Thus an average travel time of four hours on the interstate network might be assumed. Adding a location time of two hours at the reception center would give an average time to shelters of six hours.

The distribution of arrival times is dependent upon policy. Contrasted to a policy of allowing the first evacuees to seek the nearest available shelter is one of forcing the first evacuees to the farthest shelters. With the first policy, a wide distribution of arrival times at reception areas could be expected; with the latter, all would arrive at about the same time. Within the scope of this analysis these differences cannot be studied.

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A Simple Model of Population Vulnerability During Crisis Relocation. (IDA Paper P-1703) by Leo A. Schmidt, Unclassified, Institute for Defense Analyses, (Contract FEMA EMW-C-0749C)

Abstract

The objective of the study is to estimate the cost in survivors of short warning leading to attack during full nationwide crises relocation. A simulation model of traffic flow over the national interstate road network was developed to predict population vulnerability during a crisis relocation. The model predicts large initial rates of reduction in nationwide vulnerability (half the at-risk population is evacuated in 21 hours) due to the large number of risk centers initially evacuating. Problems arising in risk areas, reception areas, and over the road network to achieve the traffic plan assumptions of the model are discussed. No unreasonable problems are uncovered in achieving the major prediction of the model.

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